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Stratigraphic Evidence of Human Disturbance in Some Chesapeake Bay Tributaries

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16. ABSTRACT

Response of diatom (algal) and submerged macrophyte (angiospermous) populations to disturbance in some Chesapeake Bay tributaries over the last few centuries is interpreted from abundance of diatom frustules and presence of macrophyte seeds preserved in dated estuarine sediments. The historical record of disturbance during the time period considered includes land clearance and urbanization of the watershed resulting from human activity, as well as from periodic storms. The stratigraphic record indicates that both the diatom and submerged macrophyte populations were stable prior to European settlement. With the onset of land clearance, dramatic changes are registered that include shifts in total numbers of cells and seeds as well as in species composition. The kind of response appears to be unique for a particular type of disturbance.

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STRATIGRAPHIC EVIDENCE OF HUMAN DISTURBANCE IN SOME CHESAPEAKE BAY TRIBUTARIES

Final Report

by

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SUMMARY

The stratigraphic record indicates that for centuries prior to European settlement, diatom and macrophyte populations were fairly uniform in the Chesapeake Bay estuaries studied. Waters in tributaries draining Piedmont watersheds underlain for the most part by thick saprolites appear to have been clear with sufficient nutrients to support diverse and abundant submerged macrophyte and benthic diatom populations. In the tributary draining sandy Coastal Plain sediments, habitats were extremely oligotrophic capable only of supporting a very sparse diatom population. After initial deforestation, macrophytes and diatoms showed significant changes, many of which were coincident with historically documented changes in land and water use. Today, forests comprise about 40% of the land; sediment yield is 5 to 10 times and nutrient loading 2 to 6 times greater in agricultural than in forested watersheds (Lystrom et al. 1978). The rate of application of high-nitrate chemical fertilizers, applied to cultivated land since the mid-19th century, has quadrupled since 1900. Since the mid-20th century, sewage has increased phosphorus-loading of some estuarine tributaries by 5 to 15 times.

At oligohaline locations, strong correlations between macrophyte seed and diatom stratigraphy are coincident with land clearance and nutrient loading. At Jug Bay, in the Upper Patuxent River, the appearance of *Potamogeton epihydrus* and *Zannichellia palustris* along with an increase in flux of periphytic diatoms occurred at about the time fertilizers were added to the watershed. At Furnace Bay, in the Upper Chesapeake Bay, low diatom fluxes accompanied by the first major discontinuities in the macrophyte record followed early European land clearance. A large increase in diatom flux, dominated by the eutrophic planktonic *Fragilaria crotonensis*, around 1930, was associated with the first appearance of the eutrophic adventive macrophyte *Myriophyllum spicatum*. These population changes were coincident with the initial discharge of sewage effluent into Furnace Bay. At both locations, the proportion of planktonic diatoms has increased in recent years. At the same time, seed stratigraphy (particularly at Furnace Bay) and field surveys have documented severe declines in macrophyte populations. At mesohaline locations, the stratigraphic record shows that the effect of human disturbance is much less obvious and suggests that the greatest alteration of estuarine habitats is mainly a result of local disturbance.

Causal links between eutrophication and epiphytic diatom and macrophyte populations have been studied in lakes by Phillips et al. (1978) and summarized for Chesapeake Bay by Valentine and Stevenson (1981). Based on observations in lakes in England, Phillips et al. (1978) postulated that increased nutrient loading stimulates the growth of epiphytic and filamentous algae

which normally are suppressed by macrophyte-secreted chemicals and low nutrients. The accelerated algal growth decreases the light available to the macrophytes. If nutrient levels continue to increase, phytoplankton growth also increases thus further shading the macrophytes and resulting eventually in the elimination of both the macrophytes and associated epiphytes. In the sediments of Jug Bay and Furnace Bay, increasing flux of epiphytic diatoms with fertilizers, large increases in both epiphytic and planktonic diatoms with sewage, and a rise in planktonic species in recent years concurrent with the decline of macrophytes support the hypothesis of Phillips et al. (1978). The epiphytic diatoms do not decline as sharply as might be expected especially as the macrophytes were essentially eliminated from both areas. However, only a few epiphytic diatoms occur only on macrophytes; many can also use filamentous algae and nearby emergent vegetation as a substrate. It should be noted also that factors other than eutrophication, including a catastrophic flood in 1972 (Bayley et al. 1978) and regional increases in herbicide use since 1970 (Kemp et al. 1981) also could have played a role in the recent decline of macrophytes in the Chesapeake Bay.

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SECTION 1

INTRODUCTION

Organisms and parts of organisms preserved in estuarine sediments provide a quantitative record of changes in populations that can be compared with the historical and stratigraphic records of environmental change. Stratigraphic records of biological populations in recent sediments are particularly valuable for evaluating effects of environmental change because the historical records are often meagre, seldom quantitative, and do not allow comparisons between pre-historic and historic conditions. We investigated the history of diatom and submerged macrophyte populations preserved in sediments deposited over several centuries in 3 areas of Chesapeake Bay in order to assess the effect of human disturbance on estuarine habitats. The disturbances investigated, which have altered parts of estuaries, include sediment loading from land clearance, nutrient loading from fertilization of the cultivated landscape and the discharge of sewage effluent into estuarine waters, thermal loading from cooling water discharged by a power plant, and toxic loading from herbicide application to the farmed land and chlorination of both sewage treatment and power plants.

Fifteen sediment cores, 1 to 2 m long and 5.4 cm in diameter were collected with a piston corer at 6 locations in the upper, middle and lower Chesapeake Bay (Figure 1).

Furnace Bay is a shallow (1-2 m), oligohaline (0.5-1.0 $^{o}/oo$) embayment at the head of Chesapeake Bay. It drains a watershed of 68 km^2, underlain by unconsolidated Cretaceous sediments and saprolite derived from Piedmont crystalline rocks. Four cores were taken at this locality. Locally, major human activities since European settlement of the watershed include agriculture since 1730, fertilization of cultivated land since $\sim$ 1845, charcoal production from 1720 to 1900, sewage disposal presently 1 mgd (U. S. Army Corps of Engineers 1977) since 1918, sand and gravel mining since 1950 and the use of herbicides since the mid-1960's.

The Patuxent River at approximately the mid-section of Chesapeake Bay, is 285 km long and drains an area of $\sim$ 2400 km^2 underlain by Piedmont saprolite and unconsolidated Coastal Plain sediments. Nine cores were taken at 3 locations. Jug Bay, 84 km upstream from the mouth, is a shallow, oligohaline (0.1-1.3 $^{o}/oo$) embayment, always turbid and eutrophic. Eagle Harbor at river km 44 in the mesohaline stretch (3-9 $^{o}/oo$ salinity) is located at the end of the discharge canal of Chalk Point Power Plant ($\sim$ 900 MW) and is within the turbidity maximum (Roberts and Pierce 1976). St. Leonard Creek at river km 15, is the most saline site (9-16 $^{o}/oo$) and is outside both the turbidity

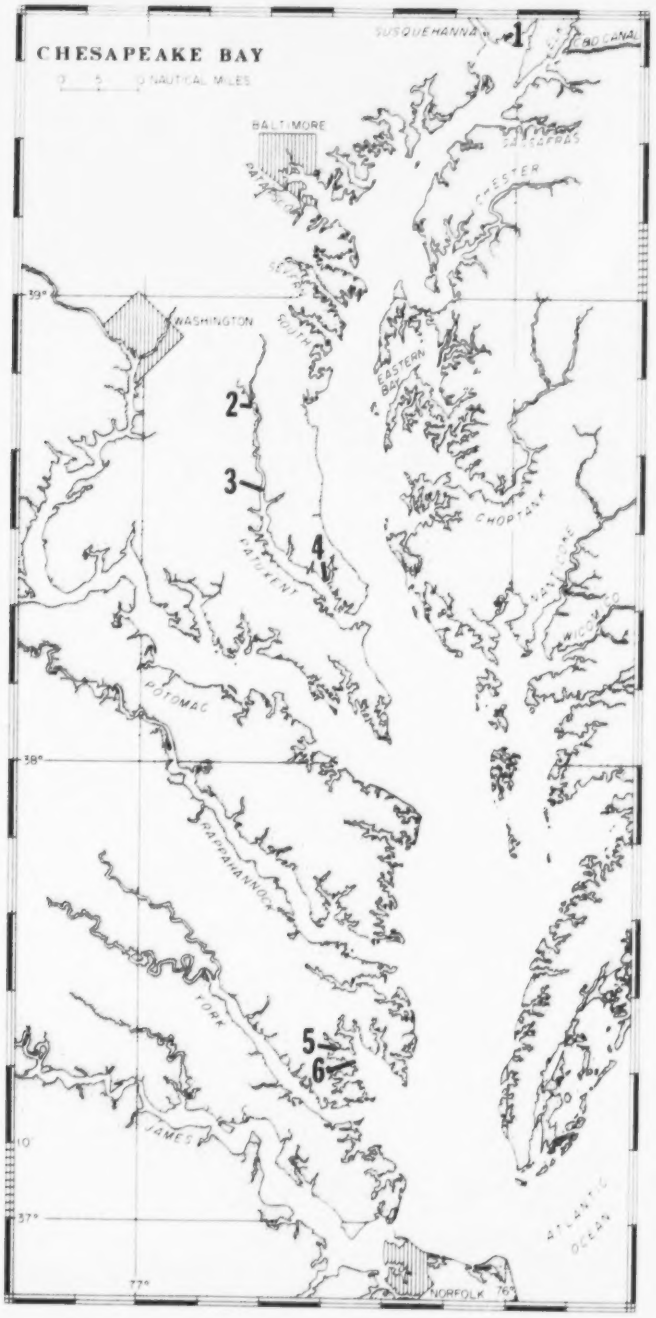

Figure 1. Map of Chesapeake Bay showing locations of areas cored: 1. Furnace Bay, 2. Jug Bay, 3. Eagle Harbor, 4. St. Leonard Creek, 5. Ware River - midstream, 6 Ware River - downstream.

maximum and the thermal plume of the power plant. The entire Patuxent watershed was farmed primarily for tobacco from 1650 to 1840 and also for grain from 1840 to the present (Craven 1925). Chemical fertilizers have been applied to cultivated land since the mid-to-late 1800's and herbicides since the mid-1960's. Intense urbanization of the upper watershed since the early 1960's has resulted in a present discharge of 35 mgd of effluent from 29 sewage treatment plants into the Upper Patuxent River (U. S. Army Corps of Engineers 1977). During the past 20 years, nutrient and suspended solid concentrations have increased throughout the estuary, with highest concentrations in the upper estuary, lower in the vicinity of Eagle Harbor and lowest at the mouth (Roberts and Pierce 1976). The Chalk Point Power Plant went into operation in 1965; since that time water temperature within the thermal plume has been raised an average of 5 to 8°C. However, the temperature increase affects primarily surface water, except at the discharge canal (1.5 km long), where mixing ensures a more or less uniform vertical temperature profile (Carter 1968).

The Ware River in the Lower Chesapeake Bay is 12 km long. Its rural watershed of 58 km^2 is underlain by sandy Coastal Plain sediments. Salinities range from 5-13 °/oo at the head to 17-20 °/oo at the mouth. Two cores were analyzed from 2 locations. The watershed was initially farmed for tobacco and since the mid-19th century primarily for grain. Chemical fertilizers have been used since the mid-to-late 19th century and herbicides since the mid-1960's. A secondary sewage treatment plant with an average discharge of 0.13 mgd was built near the head of the estuary in 1936 (U. S. Army Corps of Engineers 1977); its effects are restricted to a small area immediately downstream from the plant (VIMS, unpublished data).

SECTION 2

METHODS

Cores were extruded and split lengthwise. Splits analyzed for pollen and diatoms were divided into 1 and 2 cm intervals. The procedure for extracting pollen from the sediments follows that outlined by Faegri and Iversen (1964). Diatoms were extracted using a modified version of the method described by Funkhouser and Evitt (1959). Pollen and diatoms were each extracted from 1 cm^3 of sediment from each interval analyzed. Identifications and counts were made from several aliquots from each sample. Diatom fluxes (number of frustules deposited cm^{-2} y^{-1} were calculated by multiplying the total number of frustules per cm^3 of sediment by the appropriate sedimentation rate (cm y^{-1}). Because of the large number of species enumerated from these cores, most of which occurred < 0.5%, we included in our analyses only those species that comprised $\geq$ 3% of the population at a level. Complete vertical distributions of fluxes of all species comprising $\geq$ 3% of the population arranged into major ecological groups were plotted against time axes (Figures 3, 5, 7, 9, 11 and 13).

Splits analyzed for seeds were divided into 4 cm intervals (40-50 ml). Seeds were extracted from all samples by first disaggregating the sediment in dilute nitric acid (Godwin 1956) and then washing the sample through 20-mesh and 60-mesh sieves (0.8 mm and 0.25 mm apertures). All macrophyte seeds were identified and counted, and seed identifications confirmed using the seed reference collection at the Patuxent Migratory Bird Habitat Research Laboratory in Laurel, Maryland. The presence of seeds from continuous samples in several cores 50-100 m apart at a location was plotted against the time axis.

We measured the effect of environmental change on diatom populations by analyzing one core at each location. This was considered representative of the local population because calculated settling velocities of diatom frustules are in the range of 15 m/day and observed settling velocities range from 1 to 30 m/day (Smayda 1971). These rates indicate that diatoms are not transported far in shallow estuaries. A comparison of pollen distributions in surface sediments of the Potomac estuary with tree and shrub distributions in a broad band along the estuary show that the local patchiness of the vegetation is erased in the pollen distributions due to estuarine transport, but the regional gradients are maintained (Brush and DeFries 1981). Pollen grains are similar in size to diatom frustules, but they have a lower specific gravity and hence are likely to be transported farther than diatoms before being deposited. Thus, we expect that estuarine transport erases local variations in diatom distributions but does not result in regional mixing

We measured the effect of habitat alteration on submerged macrophytes by analyzing several cores at a location, because unlike diatoms which range from ∿ 20-150μ, the larger macrophyte seeds (1-2 mm) are not transported far from the original grass beds thus resulting in localized and patchy distributions of seeds in the sediments (Davis 1982).

Selective preservation of macrophyte seeds (Stark 1971) and dissolution of diatom frustules (Parker et al. 1977; Hecky and Kilham 1973) have been documented in some sedimentary environments. We selected for study cores with relatively intact stratigraphy and good fossil preservation. Except for poor preservation of *Potamogeton* fruits, seeds were well preserved at 3 locations. Diatoms were consistently well preserved in all cores analyzed.

In order to construct chronologic profiles of diatom fluxes and seed occurrences, sediments in the cores were dated based on changes in the vertical pollen profiles reflecting historically dated changes in regional vegetation caused by deforestation and disease (Davis 1968; Anderson 1974). In all cores, initial European settlement is recorded in the sedimentary record by an increase in percent of ragweed pollen and a corresponding decrease in the rates of oak to ragweed. During modern intensive agriculture, the percent of land cleared for agriculture increased from < 20 to 40 to 60. This is reflected in the pollen profiles by a dramatic increase in ragweed generally to between 20 to 30% of total pollen. The ratio of oak to ragweed is almost always < 1. Dates assigned to the stratigraphic horizons representing these 2 phases of land clearance (initial or early European settlement and intensive agriculture) are different for different watersheds (Figures 2, 4, 6, 8, 10 and 12). The demise of American chestnut about 1930 is reflected in pollen profiles from Furnace Bay either by the absence of chestnut or a decrease to < 1%.

Proportions of ragweed and chestnut of total pollen and the ratio of oak to ragweed pollen were plotted against depth for each core. Time lines were drawn where the changes described above occurred in the pollen profiles. Sedimentation rates were averaged between dated horizons by dividing the length of the core between dated horizons by the time between the horizons.

Uncertainties in sedimentation rates, resulting from the size of the sampling intervals, distance between sampled intervals and the error involved in assigning a precise date for an event which may have occurred over several years were calculated using the first order propagation of error (Benjamin and Cornell 1970 ; Brush et al. 1982) and are recorded in the pollen profiles (Figures 2, 4, 6, 8, 10 and 12).

Although it is necessary to use average sedimentation rates between dated horizons, we recognize that sediment accumulation was probably not uniform at all localities over the time periods studied. This can also lead to error in the calculation of population fluxes. As of now, we have no means for estimating this error.

We have assumed a 0.1 cm y^{-1} sedimentation rate for the period of time prior to European settlement. This rate is based on an average of rates

ranging between 0.05 and 0.18 cm y^{-1} derived from ^{14}C dated sediments from some Chesapeake Bay tributaries. The ^{14}C dated sediments were selected from cores where sedimentation is believed to have been continuous since the time ^{14}C dated sediment was deposited (Kraft and Brush unpublished data; Wilke et al. 1981).

SECTION 3

RESULTS

FURNACE BAY

The pollen profile (Figure 2) shows the early settlement (∿ 1730) horizon at 92 cm where percent ragweed increases from 4 to 13 and the ratio of oak to ragweed decreases from 8 to 2; the intensive agricultural horizon (∿ 1780) at 83 cm where percent ragweed increases to > 20 and the oak-ragweed ratio becomes < 1; and the demise of chestnut (∿ 1930) horizon at 28 cm where percent chestnut pollen decreases to < 1. Based on these horizons, average rates of sediment accumulation were 0.16 ± 0.04 cm y^{-1} during early settlement, 0.37 ± 0.02 cm y^{-1} during intensive agriculture when percent land cleared reached 60, and 0.58 ± 0.06 cm y^{-1} from 1930 to 1978, when the cores were collected.

Out of a total of 246 diatom species identified and enumerated from this core, 23 occurred in percentages ≥ 3 (Figure 3). Prior to European settlement, an essentially periphytic flora was dominated by *Cocconeis placentula*. Some of the species present at that time, such as *Gomphonema parvulum*, *Navicula peregrina* and *Synedra pulchella* are often found today in high-nutrient waters (Lowe 1974; Schoeman 1973). Planktonic species were extremely rare except for *Synedra pulchella* which can be either periphytic or planktonic. As Europeans cleared the land for agriculture, sediment accumulation increased at Furnace Bay. Total diatom flux was reduced to one-half its original size. Most of the original species were still present following early land clearance except *Gomphonema parvulum* and *Synedra pulchella*. Both of these species disappeared almost completely during this period. *Epithemia adnata minor* was also greatly reduced. The planktonic *Synedra rumpens* appeared and was present more or less continuously from that time on. *Navicula rhyncocephala* also made its first appearance following early settlement. Coincident with the addition of chemical fertilizers to the cultivated land, around the middle 19th century (Davis 1982), total diatom flux increased. This increase was accompanied by an increase in many species existing at that time. *Cocconeis placentula* remained dominant. Some new species, such as *Achnanthes minutissima* and the pollution-tolerant *Navicula cryptocephala* (Lowe 1974) appeared. *Gomphonema parvulum* which favors high-nutrient water reappeared. Early in this century and coincident with the discharge of sewage effluent into Furnace Bay, diatom flux increased dramatically from ∿ 1 to > 5 million. The planktonic *Fragilaria crotonensis*, considered an indicator of eutrophication (Lowe 1974; Brugam 1978) comprised 30% of the flora at that time. Kilham (1982) has shown experimentally that this species is a

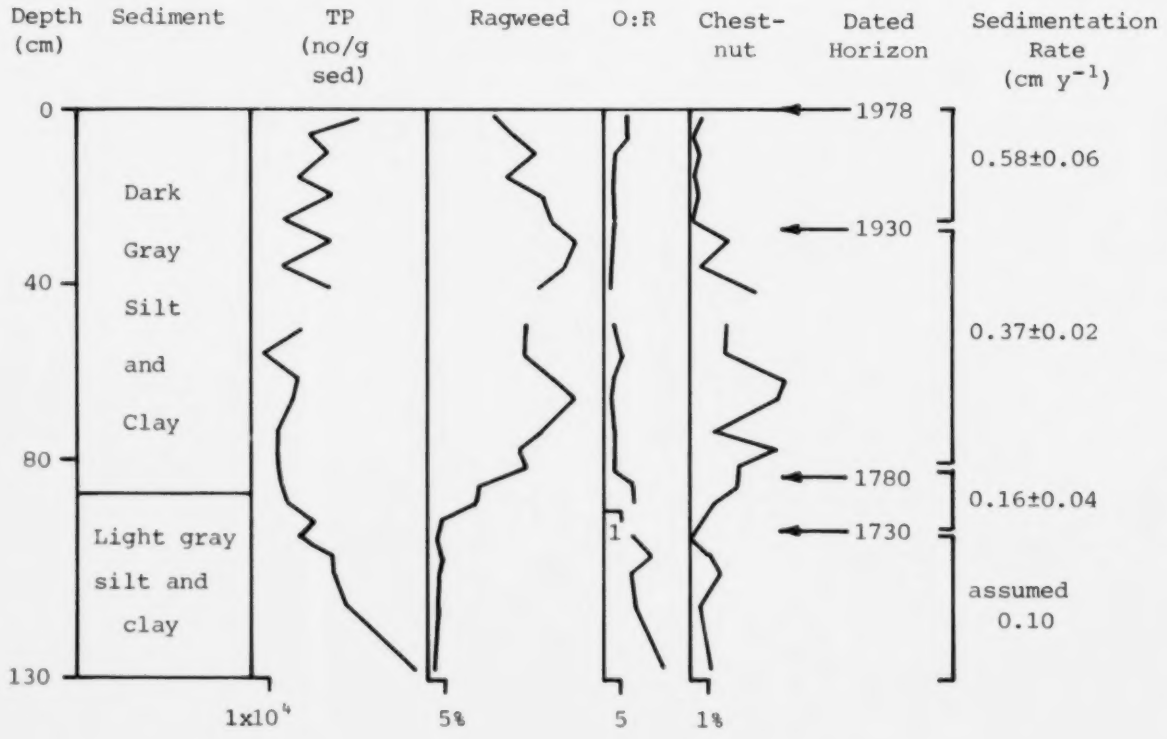

Figure 2. Pollen profile at Furnace Bay. TP - total pollen; O:R - the ratio of oak to ragweed pollen. Similar abbreviations are used in all profiles.

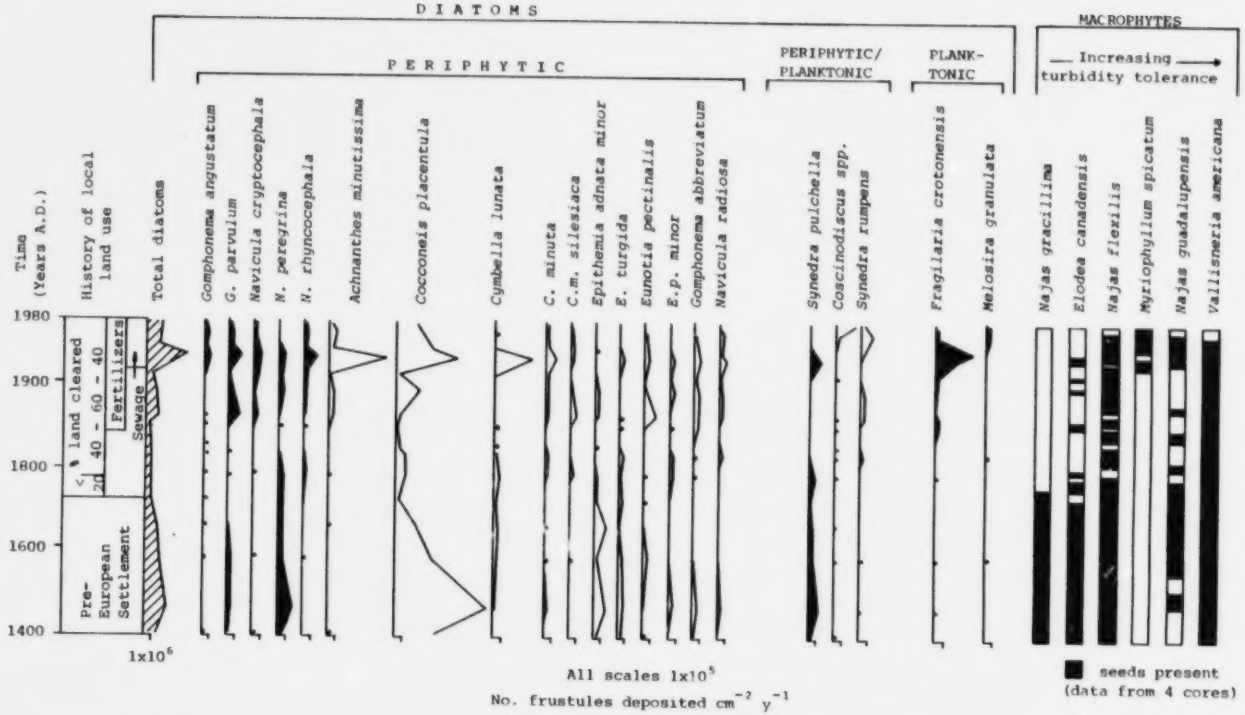

Figure 3. Diatom and macrophyte profile at Furnace Bay. Ecological groupings based on Patrick and Reimer (1966,1975), Hustedt (reprinted 1977), Lowe (1974), Schoeman (1973) and Davis and Brinson (1980). In all figures, profiles of eutrophic diatoms are colored black, and fluxes < $1x10^4$ are shown as a black dot.

good competitor for phosphorous, present in large quantities in sewage. The periphyte, *Cymbella lunata* present in small numbers but continuously until the early 19th century, when it disappeared, reappeared in large numbers in the early 20th century. The eutrophic periphyte *Synedra pulchella* also reappeared at this time and *Epithemia adnata minor* disappeared and did not return. In the early 1950's, *Fragilaria crotonensis* crashed, contributing to a decrease in total flux. It was succeeded by species of *Coscinodiscus* which can be either periphytic or planktonic and by the planktonic *Melosira granulata*. Among the eutrophic periphytes, *Navicula peregrina* disappeared and *Gomphonema angustatum* appeared.

Among the submerged macrophytes, *Vallisneria americana, Najas gracillima* and *Elodea canadensis* occurred continuously prior to European settlement, while *Najas flexilis* and *N. guadalupensis* were present most of the time. During early settlement (1730-1780), *Najas flexilis* and *Elodea canadensis* became sporadic. After 1780, as sediment accumulation doubled, *Najas gracillima* disappeared and until 1930 all of the species except *Vallisneria americana,* considered the most turbidity-tolerant of the macrophyte species (Davis and Brunson 1980), occurred infrequently. The infrequency of occurrence was particularly evident for *Najas guadalupensis* and *Elodea canadensis*. *Najas flexilis* occurred continuously from 1930 to the early 1970's. *Myriophyllum spicatum*, introduced into Eastern North America in the late 19th century, first appeared in Furnace Bay between 1930 and 1940, reappeared after 1950, and dominated aquatic macrophyte communities in this area between 1960 and 1967 (Bayley et al. 1978). The species thrives in alkaline eutrophic lakes (Seddon 1967; Lind and Cottam 1969) and can grow in moderately low light (Davis and Brinson 1980; Wentz and Stuckey 1971) in a broad range of salinities (Rawls 1964). After 1972, all native species of macrophytes disappeared from the seed record, including *Vallisneria americana* which was present continuously up to this time.

The stratigraphic record of diatoms and macrophytes suggests that prior to deforestation and cultivation of the watershed for agriculture, Furnace Bay was a shallow, clear-water embayment supporting an abundant and diverse macrophyte and periphytic diatom population. Following land clearance, the waters became turbid with increased sedimentation and populations of both macrophytes and diatoms were reduced. With the introduction of fertilizers, populations increased and included more eutrophic periphytes and free-floating diatoms. After the introduction of sewage, the embayment was transformed into a more highly eutrophic system supporting a much larger planktonic diatom population, and eventually the macrophyte populations disappeared completely from the area.

PATUXENT RIVER

Jug Bay

The pollen profile from the core at Jug Bay in the upper Patuxent River (Figure 4) shows the early settlement ($\sim$ 1650) horizon at 99 cm, where percent ragweed changes from 2 to > 5 and the ratio of oak to ragweed changes from 20 to < 10. The beginning of intensive agriculture about 1840 occurs

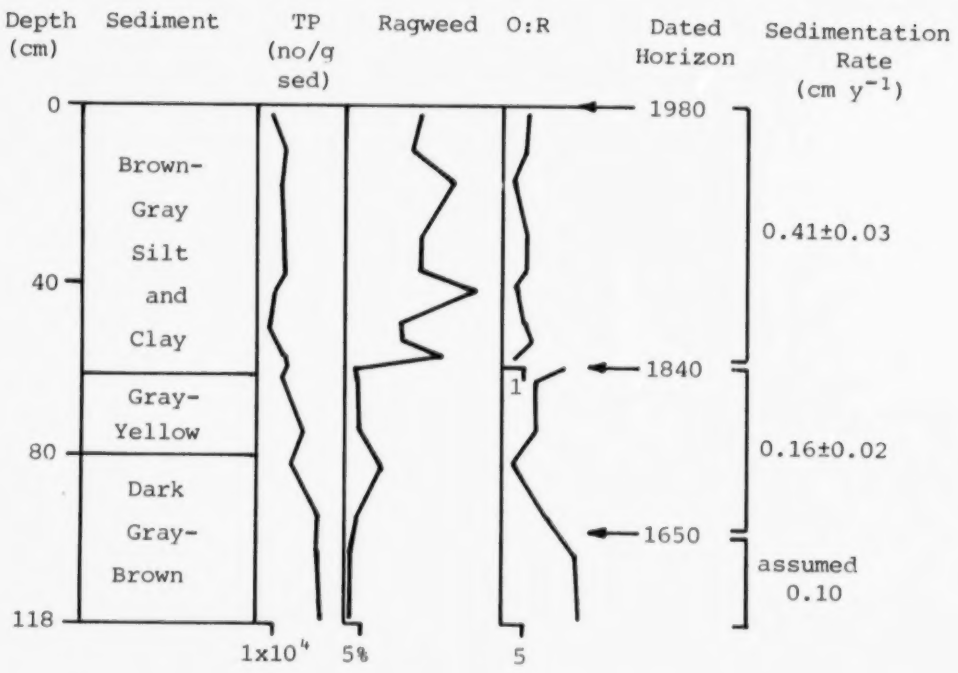

Figure 4. Pollen profile at Jug Bay in the upper Patuxent River.

at 56 cm where percent ragweed increases to > 20 and the oak-ragweed ratio is ∿ 1. Based on these horizons, the average rate of sediment accumulation which was 0.16±0.02 cm y^{-1} during the era of tobacco agriculture more than doubled to 0.41±0.03 cm y^{-1} when at least 40% of the watershed was cleared for farming.

Twenty-three of the 190 diatom species enumerated from this core occurred ≥ 3% (Figure 5). Total diatom flux remained fairly uniform before and after European settlement until the beginning of the 20th century when it more than doubled. The pre-settlement flora was a diverse assemblage consisting mainly of periphytes and including *Cyclotella memenghiniana* and the planktonic *Melosira granulata angustissima*. Both of these species are considered eutrophic (Schoeman 1973; Lowe 1974). Prior to settlement eutrophic periphytes were extremely rare. With the onset of European agriculture, a number of species appeared including the eutrophic periphyte *Navicula rhyncocephala* (Lowe 1974) and some species disappeared including *Cyclotella memenghiniana* and *Melosira granulata angustissima*, also eutrophic. Coincident with the application of chemical fertilizers to the watershed, total diatom flux began to increase. This increase was accompanied by increases in species that prefer high nutrient waters, such as *Gomphonema parvulum*, *Navicula rhyncocephala* and *N. viridula*, all periphytes. *Cocconeis placentula*, unimportant prior to the middle 19th century, became a dominant part of the flora, as did *Achnanthes lanceolata*. With the introduction of sewage effluent into the Upper Patuxent River in the 1950's, diatom flux tripled, accompanied by the appearance in large numbers of species which had not been present prior to this time or were present in very small numbers such as *Cyclotella menenghiana*, *C. kutzingiana*, *C.K. planetophora*, and *Nitzschia parvula*. Species of *Cyclotella* can occur as periphytes or plankton. The eutrophic planktonic *Melosira granulata angustissima* also reappeared at this time, and the eutrophic periphyte *Navicula rhyncocephala*, was present in large numbers. At the same time, populations of previously important periphytes, such as *Cocconeis placentula*, *Eunotia pectinalis* and *Navicula radiosa tenella* were greatly reduced.

Pre-settlement sediments contain seeds of 6 macrophyte species (Figure 5), the most common of which were *Najas guadalupensis*, *N. flexilis*, and *Elodea canadensis*. The seed record of the 18th and early 19th centuries is poorly preserved. *Najas flexilis* dropped out of the record and *Elodea canadensis* became sporadic during this time interval. By the mid-19th century, at about the time chemical fertilizers were applied to the cultivated watershed, *Potamogeton epihydrus*, which grows in mesotrophic to mildly eutrophic alkaline waters, (Hellquist 1975) appeared along with *Zannichellia palustris*. The latter is a shallow-water pioneer species in Chesapeake Bay, that tolerates very high nutrient levels (Stevenson and Confer 1978). Between 1940 and 1960, when diatom flux increased enormously, *Potamogeton epihydrus* disappeared. Field surveys show that since the late 1960's beds of submerged macrophytes declined greatly in the Upper Patuxent River (Stevenson and Confer 1978) and this is reflected in the sediments by a decrease in macrophyte seeds since 1960 (Brush et al. 1981).

The large increase in diatom flux, dominated by species of *Cyclotella*

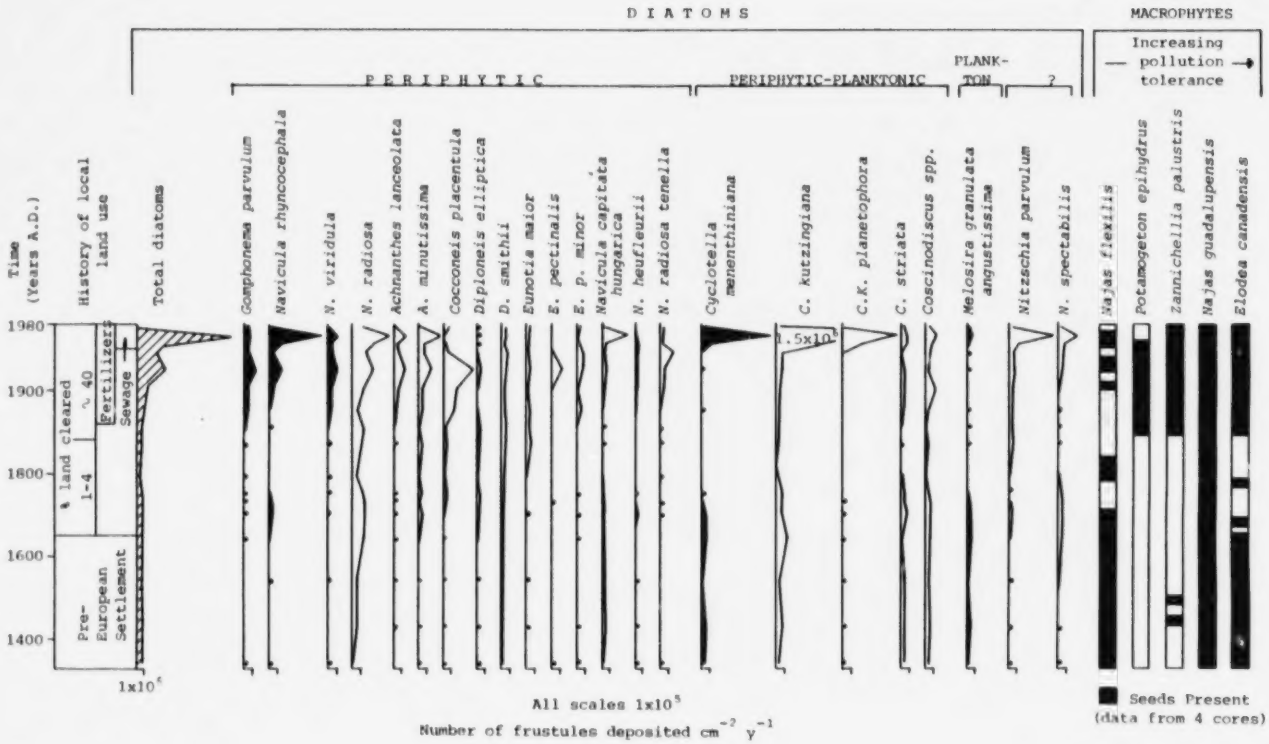

Figure 5. Diatom and macrophyte profile at Jug Bay, upper Patuxent River.

and the disappearance of submerged macrophytes are coincident with the period of intensive urbanization of the watershed and increasing discharge of sewage effluent into the river.

Eagle Harbor

The pollen profile (Figure 6) shows an early settlement (∿ 1650) horizon at 115 cm, where percent ragweed changes from < 1 to > 2 and the oak-ragweed ratio from > 35 to < 10. The horizon representing intensive clearing (∿ 1840) occurs at 60 cm, where percent ragweed increases to > 20 and the oak-ragweed ratio decreases to < 1. Sediment accumulated at a rate of 0.22± 0.02 cm y^{-1} during early settlement and like the upper part of the river more than doubled to 0.51±0.06 cm y^{-1} as a greater proportion of land was farmed.

Of the 129 diatom species identified, 23 were present at ≥ 3% (Figure 7). There is little change in total diatom flux throughout the entire core, except in the very top part, where it doubles. Nor are there any dramatic changes in the species composition throughout the core. Essentially the flora consists of a mixture of periphytes and species that can be either periphytic or planktonic and includes eutrophic species at all levels. The increase in flux in the early to mid-1970's is due mostly to a relatively large increase in *Cyclotella kutzingiana*. There are no changes in the diatom flora strictly coincident with the discharge of cooling water in the river at this location (the core was taken at the end of the Chalk Point Power Plant discharge canal).

Seed stratigraphy was not analyzed at this location because of low seed concentrations in the sediment.

St Leonard Creeks

The pollen profile (Figure 8) from the core in the downstream part of the Patuxent River indicates that the overall sedimentation rate was lower than at either up-or midstream. The early settlement horizon is at 69 cm, where percent ragweed changes from 1 to > 5 and the oak-ragweed ratio from 30 to < 5. The intensive land clearance horizon is located at 48 cm, indicated by an increase in percent ragweed to > 10 and a < 2 decrease in the oak-ragweed ratio. Thus, sediment accumulated at an average rate of 0.1± 0.009 cm y^{-1} during early settlement and was probably not very different from the pre-settlement rate. After land clearance reached ∿ 40%, sediment accumulation tripled, averaging 0.34±0.03 cm y^{-1}.

Total diatom flux is fairly uniform throughout the core (Figure 9). A total of 110 species were identified, of which 17 comprise ≥ 3% of the total population. The population consists of a mixture of periphytes and species that can be either periphytic or planktonic and includes a few species that prefer high nutrient habitats, such as *Nitzschia amphibia*, *Cyclotella bodanica*, *Meridion spp.*, and *Synedra fasiculata*. The only major change in species composition in the core was the disappearance of the eutrophic periphyte *Rhopalodia gibberula* (Lowe 1974) with the onset of agriculture, and *Cyclotella bodanica* became sporadic in the late 19th century.

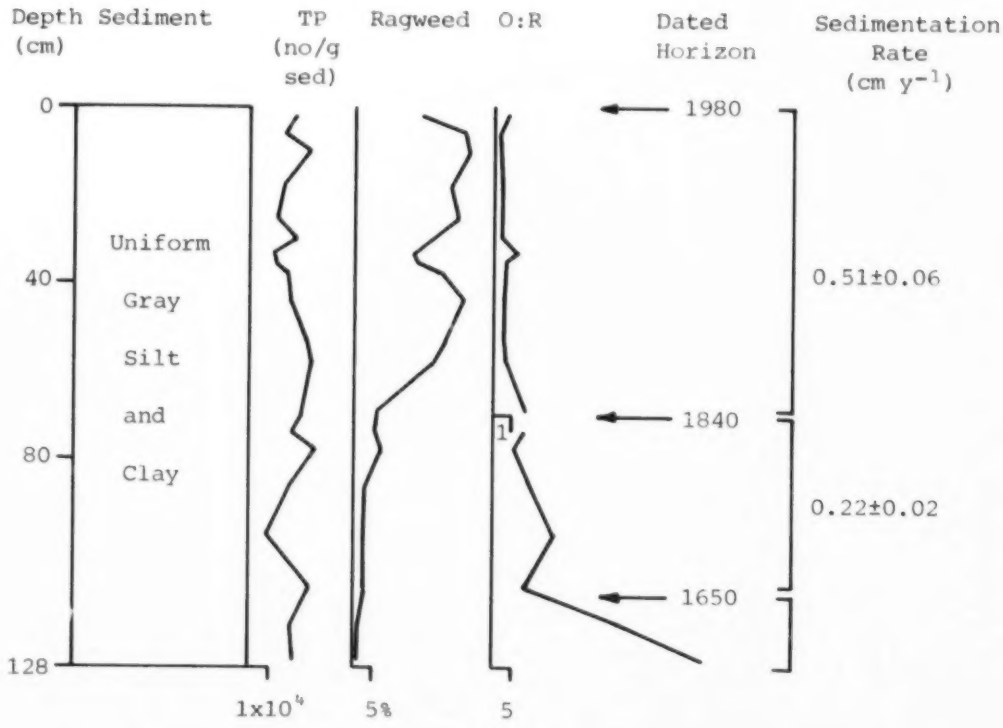

Figure 6. Pollen profile at Eagle Harbor in the middle Patuxent River.

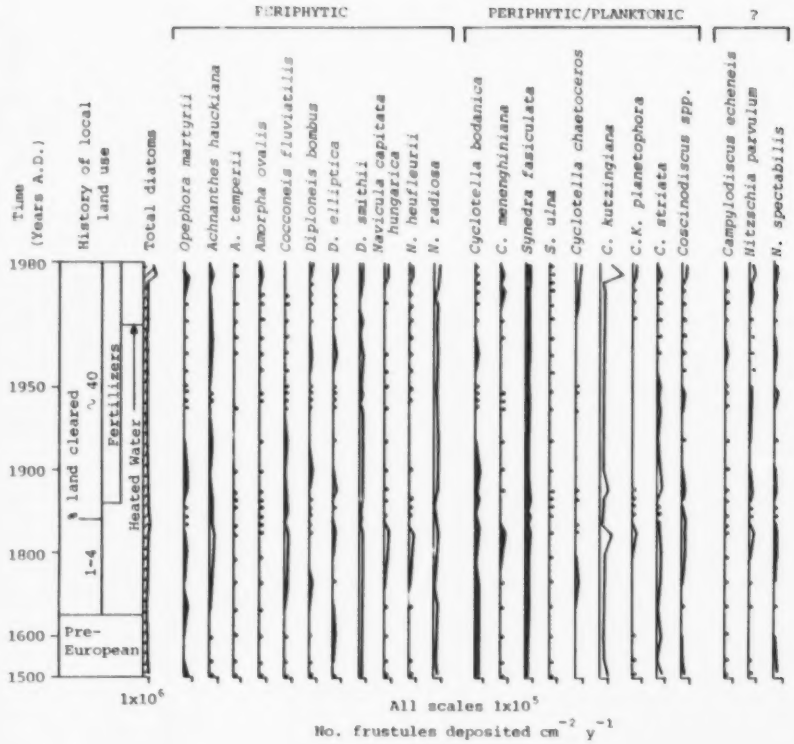

Figure 7. Diatom profile at Eagle Harbor in the middle Patuxent River.

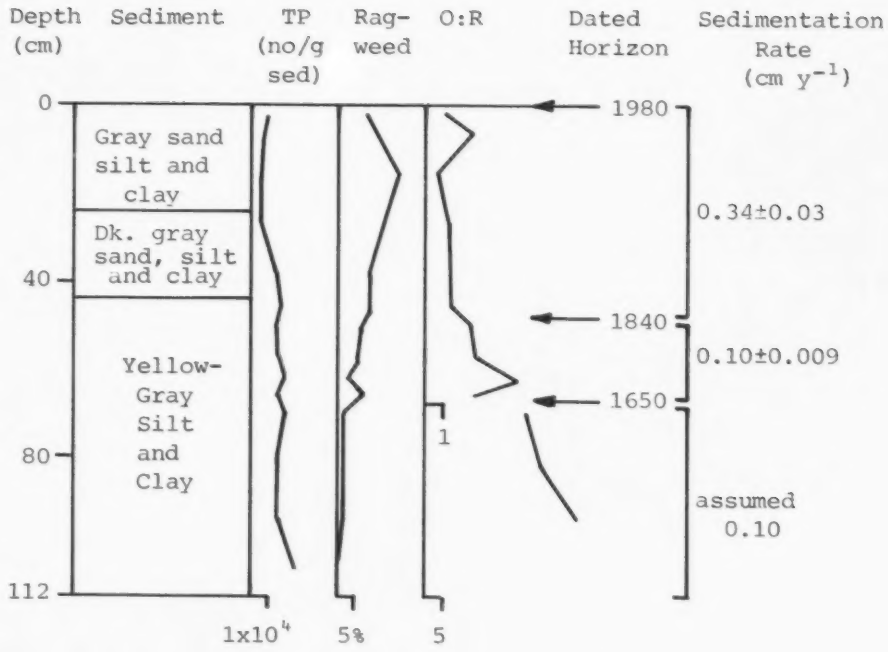

Figure 8. Pollen profile at St. Leonard's Creek in the lower Patuxent River

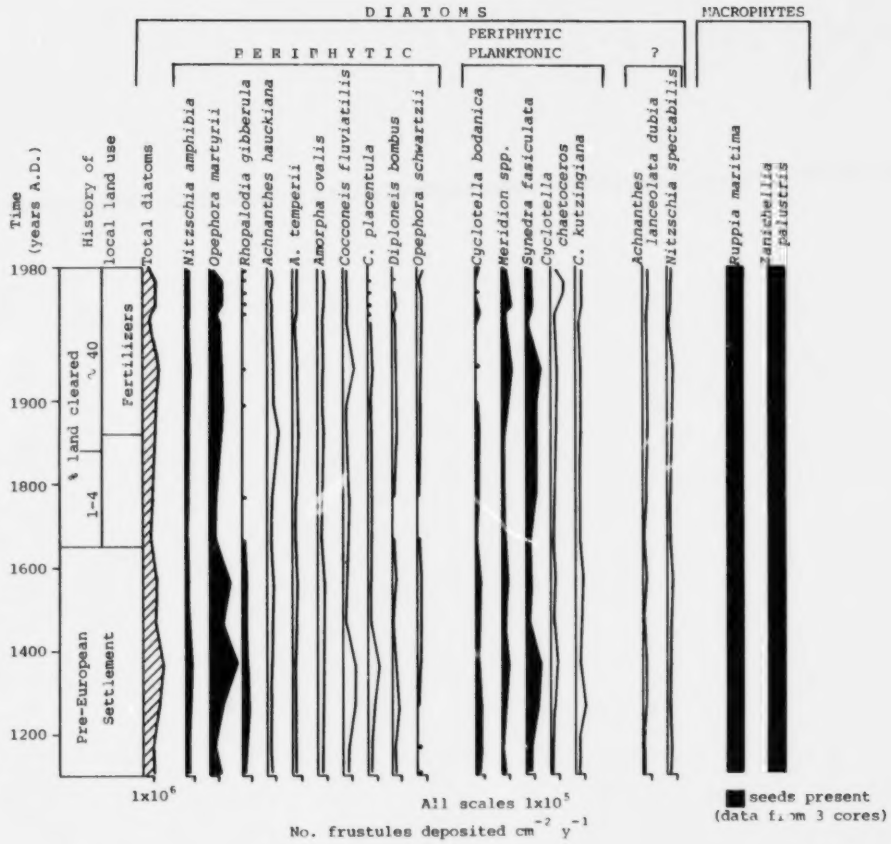

Figure 9. Diatom and macrophyte profile at St. Leonard's Creek in the lower Patuxent River.

The macrophyte seed record at St. Leonard Creek is scant, consisting of *Zannichellia palustris, Ruppia maritima, Potamogeton perfoliatus v. bupleuroidis* (not shown) and *Zostera marina* (not shown). Profiles from 3 cores suggest that *Ruppia maritima* and *Zannichellia palustris* grew locally for at least 3 centuries (Figure 9). Aerial photographs and field surveys document the decline of marcophytes in this section of the estuary since the late 1960's (Stevenson and Confer 1978; Anderson and Macomber 1979).

Diatom and macrophyte populations preserved in recent sediments indicate that the Upper Patuxent River, like Furnace Bay, was a shallow, probably clear, mesotrophic embayment supporting a diverse macrophyte and predominantly periphytic diatom population prior to European settlement. Gradually, as agriculture was succeeded by urbanization, Jug Bay changed into a highly eutrophic system dominated by species of *Cyclotella*, which can occur as plankton. At the same time, the macrophyte population was greatly reduced. The record also indicates that the deeper mesohaline part of the river was affected only slightly by human activity, principally by an increase in *Cyclotella kutzingiana* coincident with the deterioration of water quality in the late 1960's and early 1970's (Roberts and Pierce 1976). Downstream, where there has been little change in water quality, there is no detectable change in diatom and macrophyte populations over several centuries.

WARE RIVER

Midstream

The pollen profile (Figure 10) shows the early settlement horizon ($\sim$ 1650) at 63 cm where ragweed increases from < 1 to > 1 but < 5 and the ratio of oak to ragweed changes from > 10 to ~ 5. The 1840 horizon is at 52 cm based on an increase in percent ragweed to > 5 and a decrease in the oak-ragweed ratio to < 3. Based on these horizons, the sedimentation rate between mid-17th and mid-19th century was 0.06±0.009 cm y^{-1}. Because it is unlikely that the pre-settlement sedimentation rate would have been higher at least in the decades immediately preceding settlement, we assumed a 0.06 cm y^{-1} rate for pre-settlement sediments. The average rate since the mid-19th century to the present is 0.36±0.03 cm y^{-1}.

Ninety-seven diatom species were identified in this core, of which 18 occurred $\geq$ 3% (Figure 11). Total flux was never high here, but prior to European settlement, the flora was extremely sparse; however, most species which occurred later were also represented in these early sediments. After settlement, there was a slight increase in most species. The eutrophic periphyte, *Opephora martyrii* (Lowe 1974) appeared in the late 1800's at about the time fertilizers were added to the watershed. *Cocconeis placentula* also appeared about the same time. An increase in flux since 1950 is represented mainly by increases in *Achnanthes temperii* and *Cocconeis fluviatilis*.

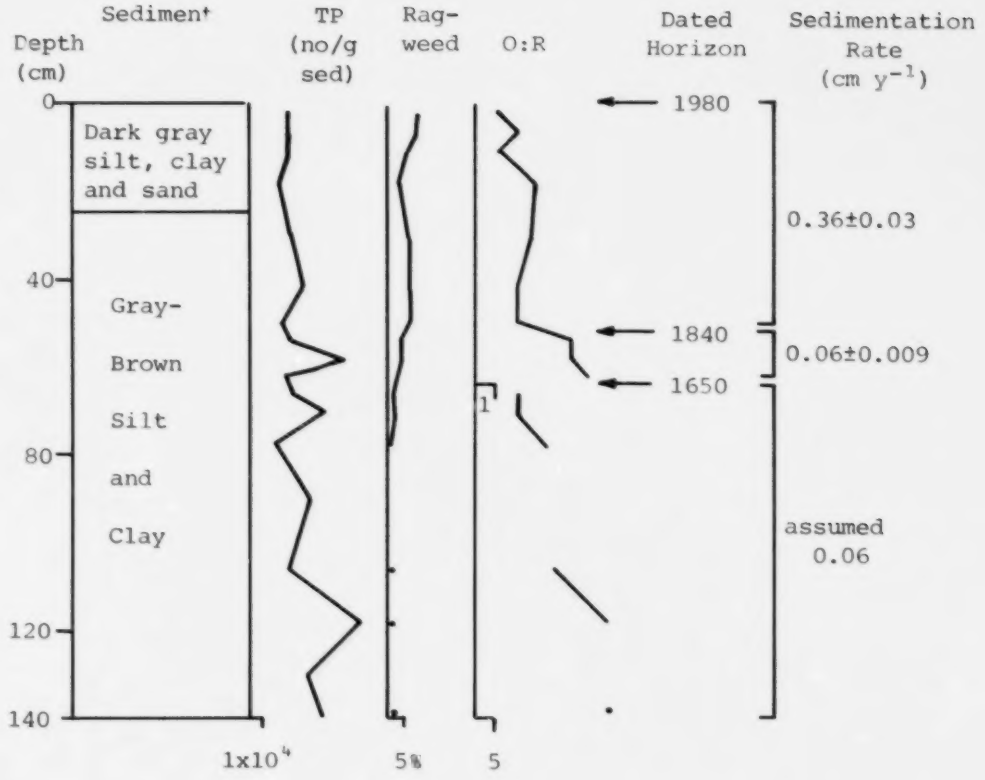

Figure 10. Pollen profile at the midstream location in Ware River.

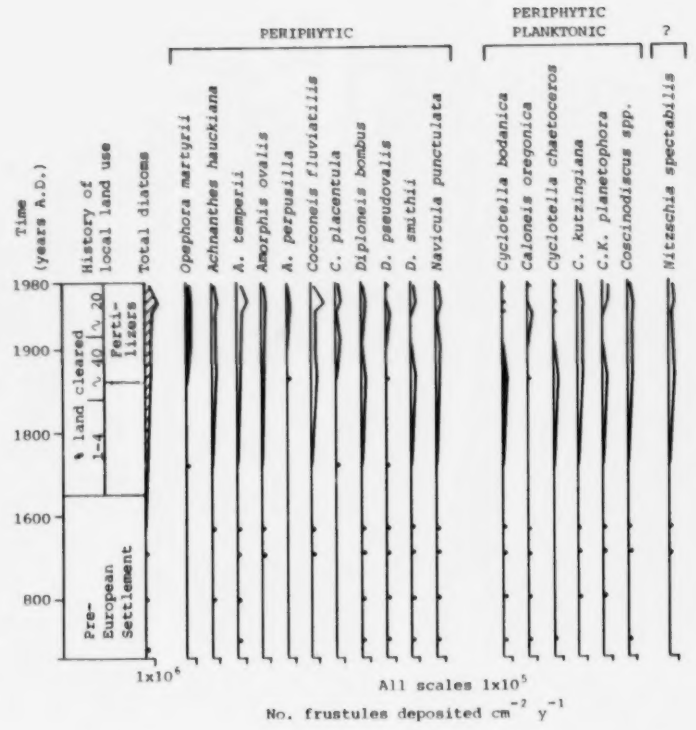

Figure 11. Diatom profile at midstream in Ware River.

Downstream

The pollen profile (Figure 12) at this location of the river shows the 1650 horizon at 88 cm based on a first appearance of ragweed. The 1840 horizon is located at 55 cm based on an increase in percent ragweed to between 5 and 15 and a decrease in the oak-ragweed ratio to < 2. These dated horizons yield sediment rates of 0.17±0.01 cm y^{-1} during early settlement and 0.39±0.03 cm y^{-1} during intensive agriculture.

As in the core taken at midstream, total diatom flux is extremely low prior to settlement (Figure 13). Ninety-seven species were enumerated; 15 occurred in percentages ≥ 3. The flora consists of several species of periphytes and 5 species of *Cyclotella*. Most of the species were present prior to European settlement. Then the flora was dominated by *Cyclotella bodanica* which is mesotrophic to eutrophic, *Diploneis smithii* and *Cyclotella kutzingiana*. The increase of flux with settlement was represented by an increase in most species and by the first appearance of *Achnanthes perpusilla*. At the time fertilizers were added to the land, *Cyclotella chaetoceros* and *Fragilaria virescens* appeared, and again flux increased with an increase in most species. Since 1950, flux has tripled due largely to increases in *Cyclotella chaetoceros, C. kutzingiana, C.k. planetophora,* and *Fragilaria virescens.* Water quality and available historical data do not provide an explanation for this sudden large increase in species that are not necessarily periphytic but may also be planktonic. Records from the other cores studied suggest that a local source of nutrients probably stimulated the growth.

The poor seed record in all cores collected in the Ware River did not allow a reconstruction of macrophyte populations in the southern region of the Chesapeake Bay.

The stratigraphic record of diatoms indicates that the Ware River, prior to European settlement, was a highly oligotrophic estuary draining a watershed underlain entirely by nutrient-poor Coastal Plain sediments. After land clearance, abundance increased particularly as chemical fertilizers were added to the watershed.

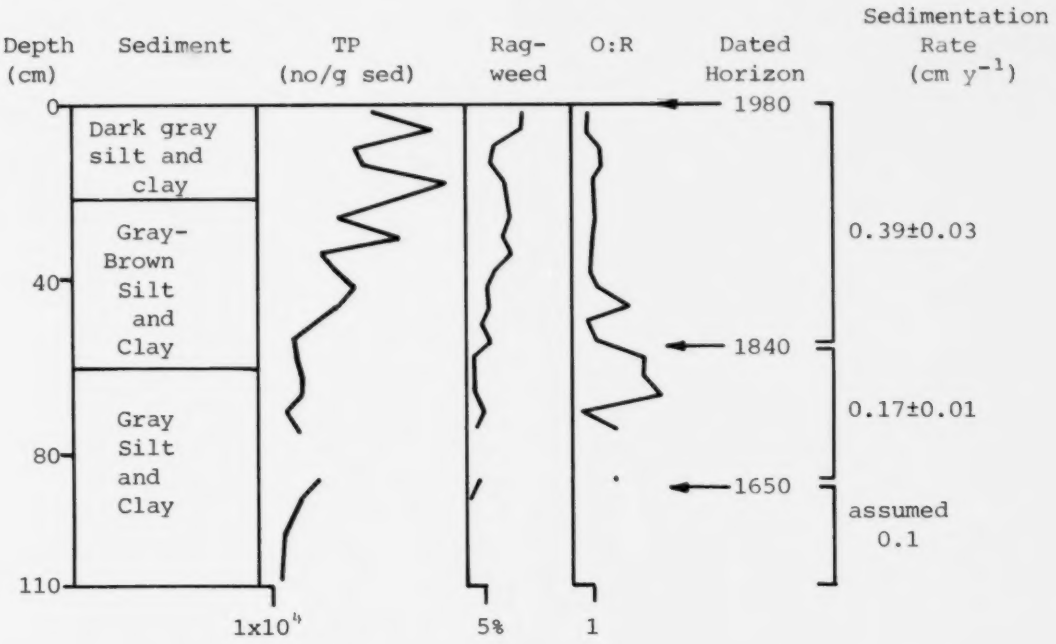

Figure 12. Pollen profile at the downstream location in Ware River.

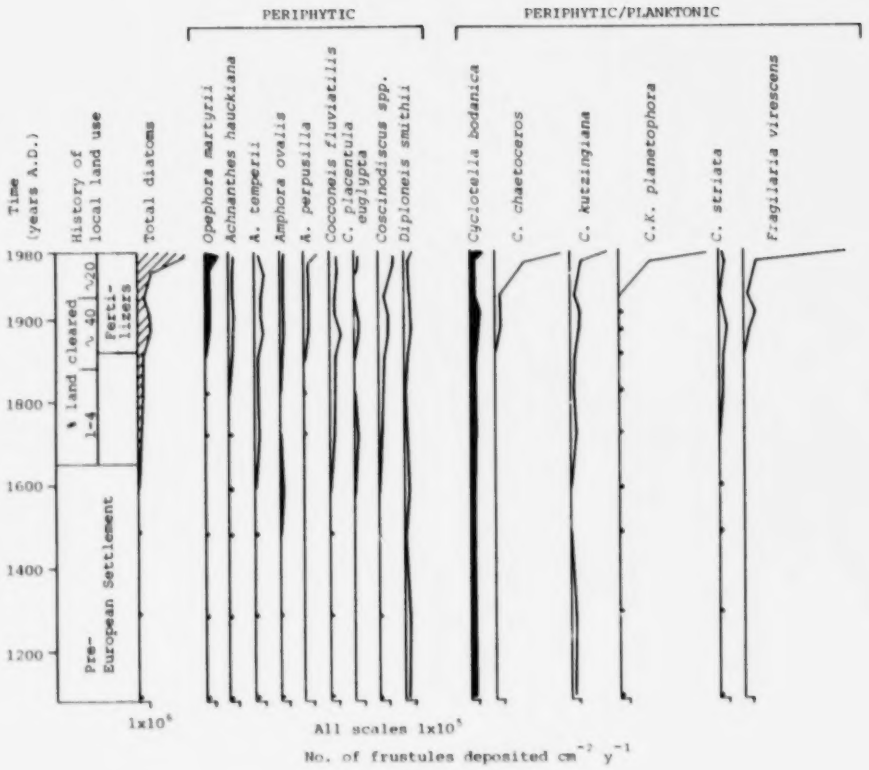

Figure 13. Diatom profile at downstream in Ware River.

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